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DESCRIPTION

MOTOR CONTROL APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a motor control apparatus and control method applied to a spindle motor or the like, which drives a machine tool.

2. Description of the Related Art

FIG. 14 shows a control block diagram of a conventional motor control apparatus having a switch unit adapted to switch between a position loop and a velocity loop according control modes to deal with a position control operation and a velocity control operation. Referring to FIG. 14, a velocity instruction means 2 in an instruction generating means 1 generates a velocity instruction signal V_{rf}, while a position instruction means 3 in the instruction generating means 1 generates a position instruction signal θ_r.

A switching means 4 is adapted to switch between a position control operation and a velocity control operation. A switching control means 4a is adapted to control switches 4b and 4c to thereby switch between a position control loop and a speed control loop. When a position control operation is requested,

a position deviation signal θ_e representing the difference between a position instruction signal θ_r having passed through the switch 4b, which is in a connected state, and a position signal θ_s, which is detected by a position detecting means 6 and represents the position of a motor 13, is inputted to a position control means 5. The position control means 5 outputs a velocity instruction operation signal V_r obtained by converting the inputted signal into a velocity instruction. Incidentally, when a position control operation is requested, or when spindle orientation is performed, a position instruction signal θ_r is outputted from the instruction generating means 1. However, when a velocity control operation is requested, the switch 4b is in a connected state. Further, the switch 4c is connected to an upper contact, as viewed in the figure. Thus, a velocity instruction signal V_{rv} outputted from a velocity instruction means 2 passes through the switch 4c.

A velocity deviation signal V_e representing the difference between a value represented by the velocity instruction signal V_{rv} having passed through the switch 4c and a derivative value, which is obtained by a differentiating means 7 from the position signal θ_s that is detected by the position detecting means 6 and represents the position of a motor 13, is inputted to a velocity control means 8.

A velocity control means 8 has a velocity proportional control means 9 and a velocity integral control means 10. When

a velocity deviation signal V_e is inputted to the velocity control means 8, the velocity deviation signal V_e is transmitted to both the velocity proportional control means 9 and the velocity integral control means 10, which respectively calculate electric current instruction values. Then, the velocity control means 8 outputs a current instruction value I_r, which is obtained by adding up the calculated electric current instruction values, to a current limiting means 11. The current limiting means 11 limits the current instruction value I_r to a maximum current value that can be outputted by a current control means 12. When a current is limited by this current limiting means 11, the current limiting means 11 instructs the velocity integral control means 10 to stop integration. The velocity integral control means 10 is configured to stop integration to thereby suppress, when electric-current limitation is canceled, occurrence of an overshoot with respect to the velocity instruction value due to unnecessary integration of the velocity deviation signal V_e generated during the electric current is limited. Thus, the current control means 12 controls electric current of the motor 13 according to the current limit value I_{r1} outputted from the current limiting means 11.

Further, FIG. 15 illustrates a technique (PCT WO03/085816A1) invented to solve the problem of the control apparatus shown in FIG. 14. In a control apparatus shown in FIG. 15, a switching means 4 of an instruction generating means

1 selects one of a position control operation and a velocity control operation according to an operation mode without performing an operation of switching between the position control loop and the velocity control loop as shown in FIG. 14. A velocity instruction signal V_{rv} generated by a velocity instruction means 2 is converted by an integrating means 14 into a position instruction signal θ_r corresponding to the velocity instruction signal V_{rv}. Further, a model position generating means 15 calculates an ideal position of the motor 13 from an equivalent position control system model, which includes a characteristic of an object to be controlled, according to the position instruction signal θ_r. When the current limiting means 11 limits the electric current to a maximum current, a position correction means 19 instructs correction of a position instruction in the motor control apparatus and operates according to the deviation between the position of the motor 13, which is calculated and outputted from the model position generating means 15, and that of the motor 13, which is actually measured by a position detecting means 6.

In the conventional motor control apparatus shown in FIG. 14, when the velocity control operation is requested, the position loop is separated therefrom, so that the motor is controlled by the velocity loop. In cases where the orientation is performed to position when the spindle is stopped, where

synchronous tapping is performed, where an operation of the spindle is performed in synchronization with another spindle, and where cutting is performed under position control, the position loop is connected thereto thereby to perform a position control operation of the motor. This motor control apparatus performs the switching every operation mode. Thus, it is necessary for smoothly switching between the velocity loop and the position loop to once reduce the velocity of the motor to a certain velocity. First, the switch 4b shown in FIG. 14 is connected. An operation of the motor is continued at a constant velocity until a velocity instruction operation signal V_r outputted by the position control means 5 is matched with a velocity instruction signal V_{rv} outputted from the velocity instruction means 2 in the instruction generating means 1. When a match therebetween occurs, it is necessary to connect the switch 4c. Thus, a switching operation requires time. Switching timing is complicated. Further, at the orientation, the velocity of the motor is once reduced to a certain velocity. Thereafter, a position instruction designating positions from a position-within-one-revolution of the motor at that time to a stopping position in the instruction generating means 1 is generated. The current of the motor is reduced by the current control means 11 with a damping time constant with which the current does not reach the current limit value. Thus, the positioning is performed. Therefore, at the orientation, time

required to reduce the velocity is long, as compared with a deceleration time needed when an ordinary velocity control operation is performed.

Further, on the condition that the velocity loop control mode may be unused, and that only the position loop control mode may be used in all operations, it is necessary to use the apparatus by reducing an acceleration or deceleration gradient within a range, in which torque is unsaturated, so as not to increase the position deviation due to the torque saturation caused by the current limitation, as not to cause an overshoot with respect to a target velocity, and as not to delay a deceleration start with respect to a deceleration instruction. Consequently, this conventional motor control apparatus has a problem in that an acceleration or deceleration time is long.

Further, the control apparatus (PCT WO03/085816A1) shown in a block diagram of FIG. 15 has been invented to solve the problem of the conventional motor control apparatus. When the current limiting means 11 limits the current of the motor to the maximum current due to saturation of a motor output voltage and to shortage of torque corresponding to an instructed acceleration at acceleration or deceleration of the motor, the position correction means 19 instructs correction of the position instruction in the motor control apparatus and operates according to the deviation between the position of the motor 13, which is calculated and outputted by the model position

generating means 15, and that of the motor 13, which is actually measured by the position detecting means 6. Thus, current limitation is canceled. In response to a subsequent position instruction, the position of the motor is corrected to a desired position when conditions for satisfactorily following the subsequent position instruction are met.

Practically, a position correction amount control means 19a in the position correction means 19 puts a switch 19b into a connected state according to a current limiting instruction I1 transmitted from the current limiting means 11. Thus, a signal representing a virtual position deviation θ_d between the position of the motor 13, which is calculated by the model position generating means 15, and that of the motor 13, which is actually measured by the position detecting means 6, passes through the switch 19b by way of a differentiating means 17 and is outputted through as an integrating means 20 as representing a correction position deviation amount θ_{cd}. Thus, in a case where the position instruction means 3 is selected by a switch 4d, correction is performed by substantially subtracting the virtual position deviation θ_{cd} from the position instruction signal θ_r. Consequently, the conventional motor control apparatus has advantages in that a follow delay from the position instruction signal θ_r in the instruction generating means 1 is apparently eliminated, and that occurrence of an overshoot is suppressed when the current limitation is canceled.

FIG. 16 includes charts illustrating changes in velocity, electric current, and position deviation in the motor control apparatus shown in FIG. 15. In a case where the velocity instruction means 2 is selected by the switch 4d, the velocity command operation signal V_r outputted from the position control means 5 is equivalent to the velocity instruction signal V_{rv} due to an excessively large value represented by the position instruction signal θ_r, which is obtained by being converted from the velocity instruction signal V_{rv}, even when the correction is conducted by subtracting the virtual position deviation θ_{cd} during current limitation is performed. Consequently, a difference from an actual velocity V_s of the motor is increased. Therefore, a large deviation is present between an electric current instruction value I_r and an electric current limitation value I_{r1} before the current limitation is performed. Thus, in a case where an output torque characteristic of the motor is recovered, time taken to reduce the current instruction value I_r to the current limitation value I_{r1} is long. Therefore, this conventional motor control apparatus has a problem in that velocity control and position control, which are performed since a moment in the vicinity of a time at which the current limitation is canceled, are delayed.

SUMMARY OF THE INVENTION

This invention is accomplished to solve the aforementioned problems. According to the invention, there is provided a motor control apparatus adapted to control a motor by using a position loop and a velocity loop according to a position signal, which represents information on a rotational position of the motor driving an object to be controlled, and according to a position deviation signal, which represents a difference between the position signal and a position instruction signal designating a rotational position of the motor. The motor control apparatus features that this motor control apparatus includes a current limiting means adapted to limit an output current to the motor and also adapted to output, when the output current is limited, a current limiting signal, a deviation limiting means adapted to obtain, when the current limiting signal is outputted and when a velocity control operation is performed, an input/output deviation of the position deviation signal and also adapted to output a signal representing the obtained the input/output deviation, and an integrating means adapted to integrate this input/output deviation. This motor control apparatus also features that when each of a velocity instruction signal and an acceleration/deceleration instruction signal is detected from the position instruction signal, an integral value of the input/output deviation signal is subtracted from the position deviation signal.

Such a motor control apparatus can solve the problem that velocity control and position control, which are performed since a moment when the current limitation is canceled, are delayed. Consequently, overshoots related to the velocity and the position can be suppressed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram of a motor control apparatus, which illustrates a first embodiment of the invention;

FIG. 2 is a flowchart illustrating a process performed by a deviation limitation means in the first embodiment of the invention;

FIG. 3 is a signal waveform diagram illustrating an operation of the first embodiment of the invention;

FIG. 4 is a block diagram of a motor control apparatus, which illustrates a second embodiment of the invention;

FIG. 5 is a signal waveform diagram illustrating an operation of the second embodiment of the invention;

FIG. 6 is a signal waveform diagram illustrating an operation of a third embodiment of the invention;

FIG. 7 is a signal waveform diagram illustrating an operation of a fourth embodiment of the invention;

FIG. 8 is a block diagram of a motor control apparatus, which illustrates a fifth embodiment of the invention;

FIG. 9 is a flowchart illustrating a process performed

by a deviation limitation means in the fifth embodiment of the invention;

FIG. 10 is a block diagram of a motor control apparatus, which illustrates a sixth embodiment of the invention;

FIG. 11 is a block diagram of a motor control apparatus, which illustrates a seventh embodiment of the invention;

FIG. 12 is a block diagram of a motor control apparatus, which illustrates an eighth embodiment of the invention;

FIG. 13 is a flowchart illustrating a control process performed by a current limit control portion 31 in the eighth embodiment of the invention;

FIG. 14 is a block diagram illustrating a conventional motor control apparatus;

FIG. 15 is a block diagram illustrating a control apparatus (PCT WO03/085816A1) invented to solve a problem of the conventional motor control apparatus; and

FIG. 16 is a signal waveform diagram illustrating an operation of the conventional motor control apparatus.

DETAILED DESCRIPTION OF THE INVENTION

First Embodiment

An embodiment of the invention is described by referring to FIG. 1. FIG. 1 is a block diagram of a motor control apparatus according to a first embodiment of this invention. Incidentally, in FIGS. 1 and 15, same reference characters designate same

or corresponding parts. A velocity instruction means 2 in an instruction generating means 1 generates a velocity instruction signal V_{rv}, while a position instruction means 3 in the instruction generating means 1 generates a position instruction signal θ_r. The velocity instruction signal V_{rv} generated by the velocity instruction means 2 is converted by an integrating means 14 into a position instruction signal θ_r corresponding to the velocity instruction signal V_{rv}. A switching means 4 in the instruction generating means 1 is adapted to switch between a position control operation and a velocity control operation. A switching control means 4e changes over a switch 4d to thereby select the position control operation or the velocity control operation. At that time, the switching control means 4e outputs a position/velocity operation switching command MOD, which represents information designating the position control operation or the velocity control operation to be selected at the changeover.

A correction position deviation amount signal θ_{cd} generated by an integrating means 20 is subtracted from a position deviation signal θ_e representing the difference between the position instruction signal θ_r outputted from the instruction generating means 1 and a position signal θ_s detected by a position detecting means 6. Then, a resultant signal is inputted to a deviation limiting means 21 as a deviation input signal θ_f. Further, the position instruction signal θ_r is converted by

a differentiating means 22 into an instruction velocity signal F_{dt}. Also, a resultant signal is converted by a differentiating means 23 into an instruction acceleration signal A_{cc}. Then, the instruction acceleration signal A_{cc} is inputted to a deviation limiting means 21 together with the position/velocity operation switching command MOD, the instruction velocity signal F_{dt}, the instruction acceleration signal A_{cc}, and a deviation input signal θ_f. The deviation limiting means 21 performs predetermined processing and outputs a deviation limiting means output value θ_g to a position control means 5. The details of the deviation limiting means 21 are described later.

The deviation limiting means output value θ_g is inputted from the deviation limiting means 21 to the position control means 5. The position control means 5 outputs a velocity instruction operation signal V_r having been converted to a velocity instruction. Further, a velocity deviation signal V_e representing the difference between the velocity instruction operation signal V_r and a derivative value of a position signal θ_s detected by a position detecting means 6, which value is obtained by a differentiating means 7, is inputted to a velocity control means 8.

The velocity control means 8 has a velocity proportional control means 9 and a velocity integral control means 10. When a velocity deviation signal V_e is inputted to the velocity control

means 8, the velocity deviation signal V_e is transmitted to both the velocity proportional control means 9 and the velocity integral control means 10, which respectively calculate a proportional current instruction value and an integral current instruction value. Then, the velocity control means 8 outputs a current instruction value I_r, which is obtained by adding up the calculated current instruction values, to a current limiting means 11. The current limiting means 11 limits the current instruction value to a maximum current value that can be outputted by a current control means 12. Further, the current control means 12 controls electric current of the motor 13 according to the current limit value I_{rl} outputted from the current control means 11.

When a current is limited by this current limiting means 11, the current limiting means 11 outputs a current limiting instruction I1 that causes the velocity integral control means 10 to stop integration. The velocity integral control means 10 is configured to stop integration to thereby suppress, when electric-current limitation is canceled, occurrence of an overshoot with respect to the velocity instruction value due to unnecessary integration of the velocity deviation signal V_e generated during the electric current is limited. Further, the current limiting means 11 also outputs the current limiting instruction 11 to the deviation limiting means 21.

The deviation limiting means 21 is described below. The

deviation limiting means 21 sends an instruction to a position correction amount control means 19a of a position correction means 19 according to information representing the position/velocity operation switching command MOD, the instruction velocity signal F_{dt}, the instruction acceleration signal A_{cc} on the conditions imposed by the following process. The deviation limiting means 21 turns on the switch 19b , outputs an input/output deviation signal V_h, and also outputs a deviation limiting means output value θ_g to the position control means 5 according to predetermined conditions.

FIG. 2 is a flowchart illustrating the process performed by the deviation limiting means 21 according to the first embodiment of this invention. The deviation limiting means 21 performs the following process and outputs a deviation limiting means output value θ_g to the position control means 5.

According to the process performed by the deviation limiting means 21, during the electric current limiting instruction I1 is performed (in step S101), in a velocity operation mode in which the position/velocity operation switching command (MOD) does not request absolute position followingness (in step S102), in a case where the instruction acceleration signal A_{cc} has a positive value ($A_{cc} \geq 0$) (in step S103), when the deviation input signal θ_f increases in a positive direction (in step S104), the deviation limiting means output

value θ_g is set at the last value of θ_g (in step S105), and an input/output deviation signal V_h is set so that $V_h = \theta_f - \theta_g$ (in step S106). At that time, the deviation limiting means 21 sends an instruction to the position correction amount control means 19a in the position correction means 19 shown in FIG. 1 to turn on the switch 19b. Thus, the input/output deviation signal V_h of the deviation limiting means 21 is accumulated in the integrating means 20 that outputs a correction position deviation amount signal θ_{cd}. This correction position deviation amount θ_{cd} is subtracted from the position deviation signal θ_e to thereby generate a deviation input signal θ_f.

Further, in a case where the instruction acceleration signal A_{cc} has a negative value ($A_{cc}<0$) (in step S109), when the deviation input signal θ_f increases in a negative direction (in step S110), the output value θ_g is set at the last value of θ_g (in step S111), and the input/output deviation signal V_h is set so that $V_h = \theta_f - \theta_g$ (in step S112).

When the input/output deviation signal V_h from the deviation limiting means 21 is set so that $V_h = \theta_f - \theta_g$, the position correction amount control means 19a of the position correction means 19 shown in FIG. 1 turns on the switch 19b. Then, the input/output deviation signal V_h from the deviation limiting means 21 is accumulated in the integrating means 20 to generate a correction position deviation amount signal θ_{cd}. This correction position deviation amount signal θ_{cd} is

subtracted from the position deviation signal θ_e. Consequently, in a case where the current instruction value reaches a limit value in the motor control apparatus due to saturation of a motor output voltage and to insufficient torque for an instruction acceleration at acceleration or deceleration of the motor, when the velocity instruction means 2 is selected by the switch 4d, and even when the value of the position instruction signal θ_r converted from the velocity instruction signal V_{rv} is too large, the input/output deviation signal V_h serving as a basis of the correction position deviation amount θ_{cd} and also representing a difference between the position deviation signal θ_e, which represents a difference between the position instruction signal θ_r and the position signal θ_s designating the position of the motor 13, and the correction position deviation amount signal θ_{cd}, is appropriate as a signal designating a correction value, as compared with a signal obtained by integration of a signal based on the virtual position deviation θ_d indicating a difference between the position outputted from the model position generating means and the position signal θ_s designating the position of the motor 13 in the case described in the prior art document (PCT WO03/086816A1), because the velocity instruction signal V_{rv} more reflects the position instruction signal θ_r. Therefore, the present embodiment has an advantage in that the difference between a value represented by the velocity instruction

operation signal V_r, which is outputted from the position control means 5, and the actual motor velocity V_s, can be suppressed from becoming too large. Consequently, the current instruction value I_r, which is thereafter obtained by the conversion, can be prevented from largely differing from the current limit value I_{r1}. Thus, the difference between the value represented by the velocity instruction operation signal V_r and the actual motor velocity V_s is difficult to increase. In a case where an output torque characteristic of the motor is recovered, time taken to reduce the current instruction value I_r to the current limitation value I_{r1} is not long. Therefore, the present embodiment can solve the problem that velocity control and position control, which are performed since a moment in the vicinity of a time at which the current limitation is canceled, are delayed.

Additionally, to prevent the output θ_g of the deviation limiting means 21 from increasing or decreasing, the difference between the velocity, which is represented by the velocity instruction operation signal V_r outputted from the position control means 5 according to the output θ_g, and the actual motor velocity V_s can be prevented from increasing. Thus, the present embodiment has an advantage in that a value represented by the velocity deviation signal V_e can be decreased by increasing or decreasing the actual motor velocity. Consequently, the current instruction value I_r, which is thereafter obtained by

the conversion, can be made to little differ from the current limit value I_{r1}. Thus, the difference between the value represented by the velocity instruction operation signal V_r and the actual motor velocity V_s does not increase. In a case where an output torque characteristic of the motor is recovered, time taken to reduce the current instruction value I_r to the current limitation value I_{r1} is not long. Therefore, the present embodiment can more effectively solve the problem that velocity control and position control, which are performed since a moment in the vicinity of a time at which the current limitation is canceled, are delayed.

Incidentally, in the other cases in the processing performed in the deviation limiting means 21, the deviation limiting means output value θ_g is set to be a value represented by the deviation input signal θ_f. Further, the correction position deviation amount θ_{cd} is not outputted, because a value represented by the input/output deviation signal V_h is set to be 0 and the switch 19b is turned off.

Furthermore, FIG. 3 is a signal waveform diagram illustrating an operation of the implemented first embodiment of the invention. In a chart shown at a top part of FIG. 3, the abscissas represent time, while the ordinates represent the velocity. A chain line represents a velocity instruction signal F_{dt}. A dot-and-dash line represents a velocity instruction operation signal V_r. A solid line represents a motor

velocity V_s. In a chart at a middle part of FIG. 3, the abscissas represent time, while the ordinates represent the electric current. A solid line represents the current instruction value. In a chart shown at a bottom part of FIG. 3, the abscissas represent time, while the ordinates represent the position deviation. Solid lines represent the correction position deviation amount θ_{cd} and the deviation within one revolution of the motor. Even in a case where sufficient acceleration of the motor is not obtained due to the current limitation, and where the deviation between the velocity represented by the instruction velocity signal V_{rv} and the motor velocity V_s is large, the deviation limiting means 21 of the invention limits the deviation limiting means output value θ_g according to a predetermined condition and controls this value so that the value represented by the velocity deviation signal V_e designating the difference between the value represented by the velocity instruction operation signal V_r outputted from the position control means 5 and the actual motor velocity Vs is neither equal to nor larger than a predetermined value. Consequently, the operation can quickly be transited to the position correction to be performed since a moment at which the current limiting is canceled after the output torque characteristic of the motor is recovered. Thus, the present embodiment can solve the problem that velocity control and position control, which are performed since a moment in the vicinity of a time at which the current limitation is

canceled, are delayed. Consequently, the present embodiment has an advantage in that overshoots related to the velocity and the position can be suppressed.

Therefore, according to the first embodiment of this invention, there is provided a motor control apparatus adapted to control a motor by using a position loop and a velocity loop according to a position signal, which represents information on a rotational position of the motor driving an object to be controlled, and according to a position deviation signal, which represents a difference between the position signal and a position instruction signal designating a rotational position of the motor. The motor control apparatus includes a current limiting means adapted to limit an output current to the motor and also adapted to output, when the output current is limited, a current limiting signal, a deviation limiting means adapted to obtain, when the current limiting signal is outputted and when a velocity control operation is performed, an input/output deviation of the position deviation signal and also adapted to output a signal representing the obtained the input/output deviation, and an integrating means adapted to integrate this input/output deviation. When each of a velocity instruction signal and an acceleration/deceleration instruction signal is detected from the position instruction signal, an integral value of the input/output deviation signal is subtracted from the position deviation signal. Thus, this motor control apparatus

can solve the problem that velocity control and position control, which are performed since a moment in the vicinity of a time at which the current limitation is canceled, are delayed. Consequently, overshoots related to the velocity and the position can be suppressed. Further, a modification of this motor control apparatus is adapted so that in a case where an output of the deviation limiting means increases even when an integral value of the input/output deviation signal is subtracted from a value represented by the position deviation signal during acceleration information represents a positive value, the output of the deviation limiting means is not increased, and that in a case where an output of the deviation limiting means decreases even when an integral value of the input/output deviation signal is subtracted from a value represented by the position deviation signal during acceleration information represents a negative value, the output of the deviation limiting means is not decreased. Thus, this modification of the first embodiment can more effectively solve the problem that velocity control and position control, which are performed since a moment in the vicinity of a time at which the current limitation is canceled, are delayed. Consequently, overshoots related to the velocity and the position can be suppressed.

Second Embodiment

Another embodiment of the invention is described by referring to FIG. 4. FIG. 4 is a block diagram of a motor control apparatus according to a third embodiment of this invention. In FIG. 4, same reference characters designate same or corresponding parts shown in FIG. 1. The second embodiment is obtained by modifying the first embodiment so that a position represented by a position instruction coincides with the actual position of the motor. The differences in configuration between the second embodiment and the first embodiment are described below. That is, the second embodiment has a position-within-one-revolution correction control portion 16 provided at the output side of the position correcting means 19. This position-within-one-revolution correction control portion 16 normalizes the correction position deviation amount θ_{cd} outputted by a position cancellation means 19 and computes a motor position-within-one-revolution deviation signal V_{rh} (that is, the control portion 16 abandons data corresponding to the number revolutions of the motor, which is equal to or more than 1, and computes a displacement amount in position within one revolution of the motor (that is, a displacement amount between a position represented by the position instruction and the actual motor position)). Then, when the control portion 16 determines that a current limitation state is canceled, and that a value represented by a current instruction is within a region of a current limit value, the

position-within-one-revolution correction amount V_{rh} is calculated so that the motor position-within-one-revolution deviation is 0. Subsequently, the position-within-one-revolution correction amount V_{rh} is added to the integrating means 20 of the position correction means 19.

An operation of the second embodiment is described below. FIG. 5 is a signal waveform diagram illustrating an operation of the second embodiment of the invention. The conditions of charts are the same as those of the charts of FIG. 3.

When the deviation limiting means 21 sets a value represented by the input/output deviation signal V_h at 0, a motor position-within-one-revolution correction is performed. The position-within-one-revolution corresponding to the correction position deviation amount θ_{cd} (that is, a position-within-one-revolution deviation corresponding to the deviation between a position represented by the instruction position and a fed-back position) is controlled to become 0.

Therefore, the second embodiment has an advantage in that the correction of a position-within-one-revolution can be performed, in addition to the advantages of the first embodiment.

Third Embodiment

This embodiment is obtained by adapting the second embodiment so that when correction is performed so that an actual

motor-position-within-one-revolution coincides with a position designated by the position instruction, a correction amount is increased at acceleration and a correction amount is decreased at deceleration so that the correction can quickly be performed. The components of the third embodiment are the same as those of the second embodiment.

An operation of the third embodiment is described below. FIG. 6 is a signal waveform diagram illustrating an operation of the third embodiment of the invention and illustrates a correction amount computation process. In FIG. 6, a first chart, a second chart, and a fourth chart from the top of FIG. 6 correspond to the chart shown at the top part of each of FIGS. 3 and 5, the chart shown at the middle part of each of FIGS. 3 and 5, and the chart shown at the bottom part of each of FIGS. 3 and 5, respectively. A third chart (a) from the top of FIG. 6 shows the position-within-one-revolution correction signal V_{rh}. The abscissas represent time, while the ordinates represent a correction amount. The position-within-one-revolution correction control portion 16 (see FIG. 4) normalizes the correction position deviation amount θ_{cd} and computes a value to be represented by the motor position-within-one-revolution deviation signal V_{rh}, after the current limitation state is canceled and the switch 39 in the position correction means 19 is opened, so that the level of the signal becomes 0. Then, a correction amount is set so that the value to be represented

by the motor position-within-one-revolution deviation signal V_{rh} corresponding to the corrected correction position deviation amount θ_{cd} is 0. Subsequently, at acceleration, a velocity waveform having a certain acceleration/deceleration pattern shown in the third chart (a) in FIG. 6 is formed so that actual position feedback is delayed behind a position instruction. A signal representing the position-within-one-revolution correction amount V_{rh} is added to the input side of the integrating means 20 of the position correction means 19. Conversely, at deceleration, a velocity waveform having a certain acceleration/deceleration pattern shown in the third chart (a) in FIG. 6 is formed so that actual position feedback is advanced from a position instruction. A signal representing the position-within-one-revolution correction amount V_{rh} is added to the input side of the integrating means 20 of the position correction means 19. A total correction amount determined by using the velocity waveform having a constant acceleration/deceleration pattern is set by reducing the correction position deviation amount θ_{cd} at acceleration and by increasing the correction position deviation amount θ_{cd} at deceleration to set at the value of a distance from a position-within-one-revolution of 0 so that the corrected position-within-one-revolution is 0. Thus, the correction amount is determined by the certain acceleration/deceleration pattern. Consequently, the third embodiment can quickly

determine the correction amount and also can quickly perform the correction of the position-within-one-revolution.

Therefore, according to the third embodiment of the invention, the correction of the position-within-one-revolution can quickly be achieved, as compared with the second embodiment.

Fourth Embodiment

This embodiment is obtained by adapting the third embodiment so that when the correction is performed to make the actual motor position-within-one-revolution coincide with the position designated by the position, a correction pattern used to correct a position-within-one-revolution correction signal is changed according to a feedback velocity to quickly perform the correction. The components of the fourth embodiment are the same as those of the second embodiment and the third embodiment.

An operation of the fourth embodiment is described below. FIG. 7 is a signal waveform diagram illustrating an operation of the fourth embodiment of the invention and illustrates a correction amount computation process. A chart (a) shown at a top part of FIG. 7 is the same as the third chart shown in FIG. 6, which illustrates the position-within-one-revolution correction signal V_{rh}. A chart shown at a middle part of FIG. 7 is the same as the fourth chart shown in FIG. 6. A graph

(b) shown at a bottom part of FIG. 7 illustrates acceleration and the deceleration gradients in the position-within-one-revolution correction signal V_{rh}. The abscissas represent the velocity, while the ordinates represent the gradient (the acceleration). A solid line shows a first case. A chain line shows a second case. A dot-and-dash line shows a torque characteristic of the motor.

As shown in the chart (a) at the top part of FIG. 7, a maximum velocity in a correction pattern of the position-within-one-revolution correction signal V_{rh} is determined at a certain rate (γ) (for example, 10%) with respect to a velocity feedback value at an actual correction starting moment. Further, the gradient (the acceleration), at which the velocity increases until reaches a maximum velocity, in the correction pattern used to correct the position-within-one-revolution correction signal is determined according to the output torque characteristic of the motor, as indicated by the dot-and-dash line shown in the bottom part (b) of FIG. 7. A continuous output torque characteristic can be selected by taking a certain margin into account as illustrated in the first case (indicated by the solid line) shown in the graph (b) at the bottom part of FIG. 7 in a case where margins of processing-time and memory-capacity are provided in the control apparatus. However, in a case where no margins of processing-time and memory-capacity are provided

in the control apparatus, a stepwise characteristic can be determined just like the second case (indicated by the chain line). Consequently, the position-within-one-revolution correction to be performed since a moment, at which the current limitation is canceled, can stably and quickly be achieved.

Therefore, the fourth embodiment of this invention can stably and quickly perform the position-within-one-revolution correction, as compared with the second embodiment.

Fifth Embodiment

FIG. 8 is a block diagram of a motor control apparatus according to another embodiment of this invention. In FIG. 8, same reference characters designate same or corresponding parts shown in FIG. 1. The fifth embodiment deals with a case, in which the spindle motor is an induction motor intended to obtain desired characteristics at a high velocity and at a low velocity, by switching between windings. The fifth embodiment is described below.

A winding switching means 24 in an instruction generating means 1 is adapted to output, when switching between the winding of the motor, a winding switching request command CA. A correction timing timer 25 is a timer adapted to receive this winding switching request command CA and also adapted to arrange timing with which the motor position-within-one-revolution correction is performed upon completion of switching between

the windings. Incidentally, the command CA is transmitted also to the deviation limiting means 21. FIG. 9 illustrates a process to be performed by the deviation limiting means 21 when receiving this winding switching request command CA. When receiving the winding switching request command CA, the motor control apparatus turns a servo off and shuts off electric current to be supplied to the motor. In this state, the deviation limiting means 21 limits a deviation limiting means output value θ_g so that the level of the velocity deviation signal V_e is 0. A practical example of the position deviation limitation is similar to a processing operation performed during the current limitation (in step S101) in the velocity operation mode (in step S102) designated by the position/velocity operation switching command (MOD)50. Discrimination conditions for causing the apparatus to perform an operation are changed from those shown in steps S101 and S102 in FIG. 2 to the condition that the level of the velocity deviation signal V_e is not 0 under the winding switching request, as shown in steps S119 and S120. In a case where this condition shown in steps S119 and S120 is employed, the deviation limiting means 21 limits increase in the deviation limiting means output value θ_g and controls the level of the velocity deviation signal V_e to become 0, and consequently controls the level of the current instruction value I_r to become 0.

Incidentally, in this time period, the switch 19b is on,

so that the correction position deviation amount θ_{cd} is computed to thereby perform the deviation limiting process. Further, in a case where the winding switching is completed, and where the servo is turned on again, the position-within-one-revolution correction is started so that the motor position-within-one-revolution deviation corresponding to the correction position deviation amount θ_{cd} is 0. However, there is possibility that just after the start of the correction, the current limitation may be caused again to start the processing to be performed at the deviation limitation again. Thus, the correction timing timer 25 arranges the timing with which the position-within-one-revolution correction is performed. Consequently, even when receiving a motor winding switching request command, so that the servo is temporarily turned off and that the switching process is performed, a stable operation can be performed.

Therefore, in addition to the advantages of the second embodiment, the fifth embodiment of the invention has an advantage in that a stable operation can be performed even when a motor winding switching request command is received, so that the servo is temporarily turned off and that the switching process is performed.

Sixth Embodiment

FIG. 10 is a block diagram of a motor control apparatus

according to another embodiment of this invention. In FIG. 10, same reference characters designate same or corresponding parts shown in FIG. 4. Hereinafter, the differences between the sixth embodiment and the second embodiment shown in FIG. 4 are described. Referring to FIG. 10, in a velocity operation mode (a mode in which absolute position followingness is not requested), a command PHS, which indicates that the motor position-within-one-revolution correction is also unnecessary, is inputted to the motor control apparatus from a position-within-one-revolution adjustment suppressing means 26. The command PHS is transmitted to a switch 27 in the position correction means 19 and to a switch 28 between the deviation limiting means 21 and the position control means 5. Usually, the switch 27 is connected to an input/output deviation signal V_h outputted from the deviation limiting means 21. However, when the command PHS is inputted, the switch 27 is changed over and is connected to a side opposite to the input/output deviation signal V_h. The side opposite thereto is connected to a signal representing a derivative value of the deviation between an ideal position of the motor 13, which is calculated by the model position generating means 15 according to a position instruction signal θ_r from an equivalent position control system model including a characteristic of an object to be controlled, and the actual position of the motor 13, which is measured by the position detecting means 6. Thus, in the case where the

position/velocity operation switching command MOD designates the velocity operation at that time, the ideal position of the motor 13 is calculated. A signal representing the derivative value is generated according to the deviation between the ideal position and the actual position of the motor 13, which is measured by the position detecting means 6. Further, in a case where this command PHS is inputted, the switch 28 is changed over and is connected to a deviation input signal θ_f so that the deviation input signal θ_f is inputted directly to a position controller 5 without being passed through the deviation limiting means 21.

Therefore, according to the sixth embodiment of this invention, in a case where the motor position-within-one-revolution correction is not requested, an acceleration or deceleration time can be minimized according to the output torque of the motor.

Seventh Embodiment

FIG. 11 is a block diagram of a motor control apparatus according to another embodiment of this invention. In FIG. 11, same reference characters designate same or corresponding parts shown in FIG. 10. Hereinafter, the differences between the seventh embodiment and the fifth embodiment shown in FIG. 10 are described. Referring to FIG. 11, a ready-off mode request command RDY requesting a ready-off mode, in which the control

of the motor by using the motor control apparatus is unnecessary, is inputted. During the ready-off mode, the instruction generating means 1 performs a process of adjusting a value represented by the position instruction signal θ_r to the actual position of the motor, which is represented by the position signal θ_s. The ready-off mode request command RDY is inputted also to the integrating means 20 in the position correction means 19. When the command RDY is inputted thereto, an integral amount in the integrating means 20 is set to be 0. That is, the correction position deviation amount θ_{cd} is set to be 0.

Therefore, according to the seventh embodiment of this invention, the control system can be suppressed from being unstabilized by an accumulated correction position deviation amount θ_{cd}, which exceeds the quantity of data that can be stored in a memory or the like provided in the motor control apparatus.

Incidentally, in a case where features of the seventh embodiment, which are added to the sixth embodiment, are added to the first embodiment, advantages similar to the aforementioned advantages of the seventh embodiment can be obtained.

Eighth Embodiment

FIG. 12 is a block diagram of a motor control apparatus according to another embodiment of this invention. In FIG. 12, same reference characters designate same or corresponding

parts shown in FIG. 11. Hereinafter, the differences between the eighth embodiment and the sixth embodiment shown in FIG. 11 are described. The eighth embodiment is obtained by modifying the sixth embodiment so that a current limit value control means 31 changes an electric current instruction value I_{r1}, which are outputted by the current limiting means 11 based on predetermined conditions, according to the correction position deviation amount θ_{cd}.

FIG. 13 is a flowchart illustrating a control process performed by the current limit value control means 31 in the seventh embodiment of this invention. In a case where the position/velocity operation switching command MOD designates a velocity operation mode in which the position/velocity operation switching command MOD does not request absolute position followingness (in step S121), and where a droop cancellation amount θ_{cd} is equal to or more than a predetermined value (α%) of the quantity of data provided in the motor control apparatus (in step S122), maximum values of the current instruction value Ir1 outputted by the current limiting means 11 are respectively set corresponding to an acceleration time and a deceleration time so that the limit value at acceleration is reduced from the maximum value at the deceleration with a certain ratio (β%) (in step S123). Generally, at deceleration, the deviation from a value represented by the position instruction is large. The correction position deviation amount

θ_{cd} is accumulated having a sign thereof at deceleration. Thus, in a case where the correction position deviation amount θ_{cd} becomes close to the quantity of data provided in the motor control apparatus in a longtime operation, an accumulated value thereof is maintained at a constant value by increasing a torque limit value at acceleration and by setting the correction position deviation amount θ_{cd} at the acceleration to be larger than the cancellation amount at deceleration. Incidentally, in a case where the correction position deviation amount θ_{cd} becomes equal to or less than a certain predetermined value (γ%) of the quantity of data provided in the motor control apparatus once again (in step S124), the limit value of the current limiting device 11 is put back to an original predetermined value (in step S125).

Therefore, the eighth embodiment of this invention has an advantage in that the control system can be more effectively suppressed from being unstabilized by an accumulated correction position deviation amount θ_{cd}, which exceeds the quantity of data that can be stored in a memory or the like provided in the motor control apparatus, as compared with the seventh embodiment.

Incidentally, in a case where features of the eighth embodiment, which are added to the seventh embodiment, are added to the first embodiment, advantages similar to the aforementioned advantages of the eighth embodiment can be

obtained.

A motor control apparatus according to this invention is suitable for use in controlling a spindle motor of NC apparatus.